Wind-Diesel Hybrid Design Project: a Case Study of Masirah Island in Oman

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November 20, 2021

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***Abstract*— Single or no transmission line network connected to the power grid is the major characteristics of rural area power supply; resulting in unreliable and unsecured power supply. While in villages or islands that are off-grid, stand-alone systems are the alternatives energy generation procedure used. Recent penetration of renewables into the power generation has enable its application in both urban and rural areas in order to minimise cost, and make the system more reliable and secured. Thus, integrated wind-diesel hybrid power system with pumped storage system in a remote island of Jazirat Masirah in Oman would be of high benefits. Different wind-diesel hybrid systems were designed and analysed using HOMER software, in a bid to find a better and lasting solutions to the power problem of the island while considering the economic and technical benefits. It was found that, a hybrid system comprising of two E-48 wind turbines, one diesel generator set and one pumped hydro storage can meet the island's load demands at a cheaper rate by producing output power of about 9.3MW.**

Index Terms*— *Hybrid energy system, Pumped hydro energy storage, Cost of Energy (COE), Annual capital cost (ACC), HOMER, Average AC

I. Introduction

Good policies for renewables and sustainable energy management are the basis upon which reliable power generation from these abundant resources relied. Several issues regarding the exploitation of these resources, especially in the developing countries were reviewed and discussed by [1]. The reason is due to the clean nature, environmentally friendly and abundant supply of the resource which cannot be exhausted like the fossil fuel. Thus, the importance of energy towards development and growth of any economy can never be over emphasized.

In his study [2] described hybrid renewable energy system as a power network or system comprising of two or more renewable energy sources for optimum and secured power supply. Wind and solar hybrid systems are the most common because of their abundance as well as flexibility in their integrations. DC buses are connected to the renewable energy hybrid system to enhance the adaptability of the energy.

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Recently, wind turbine technology has been seen to be more promising than solar PV technology although, both are intermittent in their generated power as a result of the varying climate, weather and season in a year. There are still some remote island cities in the world which have no access to the national grid and solely depend on diesel generators to meet the load demand of the island.

Based on these, the following study aims at designing and analyses of wind-diesel hybrid power system with pumped hydro storage for Jazirat Masirah island in Oman using HOMER software. The island is situated at 15km away from the coastal region of Al Wusta in Oman's Central [3]. There is presence of abundant renewable energy resources in the island due to the steady Khareef winds blowing in the Southwest along Oman's coast [4]. As cited by [3, 4], the current situation of Masirah Island is the fact that the entire load demand of the island is met by ten (10) diesel generators with power rating ranging from 265kW to 3136KW located at the central power station in which the installed total capacity exceeds 8200kw. Masirah Island power system is made up of 54% residential load demands, 40% government and commercial usage and 6% industrial loads. The load energy demand increases significantly during the summer months in order to meet the air-conditioning load. The map of the study area is shown in the Fig. 1.

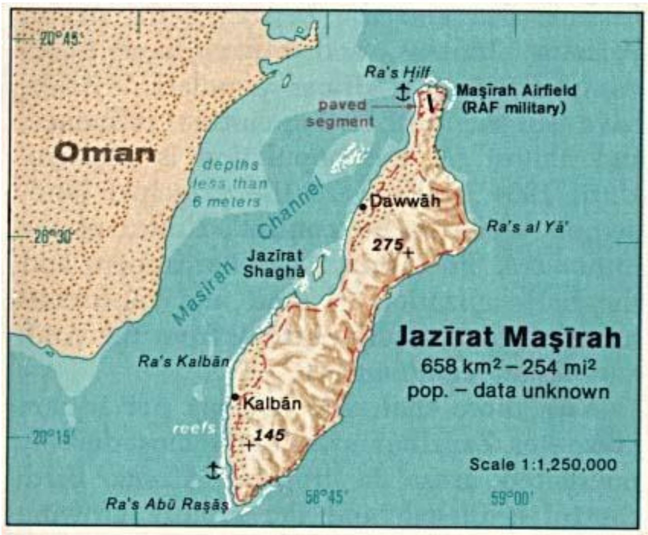

Fig. 1. Map of Jazirat Masirah Island in Oman [3]

II. Theory

A. Mean Wind Speed

The most popularly and simplest used indicator of wind production potential is the mean wind speed. In [5] it was reported that an annual mean wind speed of about 4 m/s at 10 m height is considered economically viable for a utility-scale wind farm. This can be obtained using the following expression:

$$m_i = \frac{1}{n}\sum_{j=1}^{n} v_i \quad (1)$$

Where $\boldsymbol{n}$ and $\boldsymbol{v_i}$ represents sample size and wind velocity recorded for the $\boldsymbol{i_{th}}$ observation.

B. *Wind Probability Distribution*

For a wind profile with a large sample size, it is important to group the wind speed data into intervals to create a histogram of the distribution [6]. The observed wind speed probability being within an interval can be written as:

$$f(v) = \frac{\Delta T}{t_0} \quad (2)$$

With $\boldsymbol{f(v)}$ representing the probability distribution function, while $\boldsymbol{\Delta t}$ represents wind speed duration in hours and t_0 represents the total hours during the year.

C. *Available Power in the wind*

The total power available in the wind is given by the relation:

$$P_w = \frac{1}{2}\rho V^3 \quad (3)$$

The mechanical power extracted from the wind is given by the relation:

$$P_w = \frac{1}{2}\rho A V^3 \quad (4)$$

Where all the parameters have their usual meanings.

D. *Wind Energy*

The amount of energy that is harnessed by wind turbine depends on the power in wind speed and the distribution of wind speed at the location. The average energy produced (ΔE) during Δt period is expressed:

$$\Delta E = P \times \Delta t \quad (5)$$

With $\boldsymbol{f(v)}$ representing the probability distribution function, while $\boldsymbol{\Delta t}$ represents wind speed duration in hours and t_0 represents the total hours during the year.

III. Materials And Methods

The wind speed data and the load demand for the period of one year (2007) are shown in the following figures. The given load and wind speed data are used for the analyses.

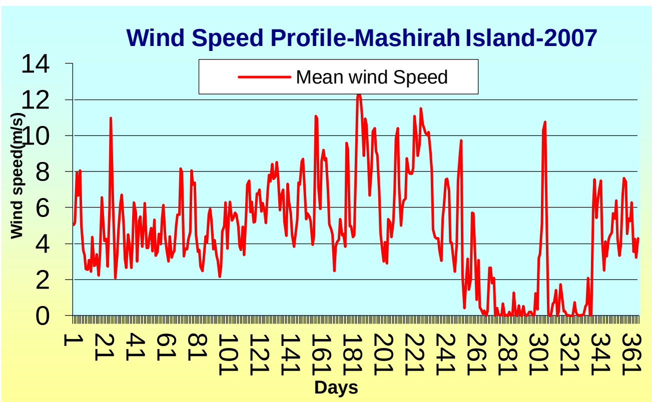

Fig. 2. Wind speed profile for Mashirah Island 2007 [7]

HOMER energy software was used for the systems design, simulation and analyses. This is because of its capability to perform the required tasks. The given annual wind speed profile and load demand for the study area were imported from the reference source file into the software. Three different hybrid topologies were designed and analyzed in order to find the best fit for the location's load demand and economic viability. In the research, three different specifications for the diesel generators were used, Enercon (E-48) wind turbine was selected and finally a pumped hydro storage of 245kW was also used. The specifications for each of the components as used in the software are shown in the corresponding figures. Finally, the systems were simulated and the output obtained were analyzed, presented and discussed in the next section. A diesel price benchmark of **0.48$/litre** was used throughout the study.

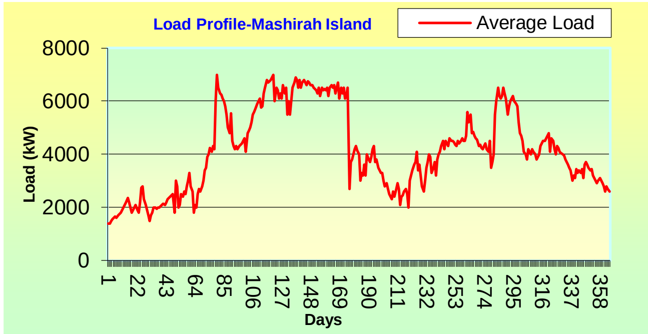

Fig. 3. Load profile for Mashirah Island 2007 [7]

Table I shows the parameters of the complete designed hybrid systems.

TABLE I. PARAMETERS USED FOR THE HYBRID SYSTEM

Component	Name	Size	Unit
Generator #1	Generic Large Genset (size-your-own)	1,325	kW
Generator #2	Generic Large Genset (size-your-own) (1)	3,136	kW
Generator #3	Generic 1MW Fixed Capacity Genset	1,000	kW
Storage	Generic 245kWh Pumped Hydro	1	strings
Wind turbine	Enercon E-48 [800kW]	1	ea.
System converter	Generic large, free converter	9,999,999	kW
Dispatch strategy	HOMER Cycle Charging		

In Fig. 4 the schematic diagram of the complete system is shown.

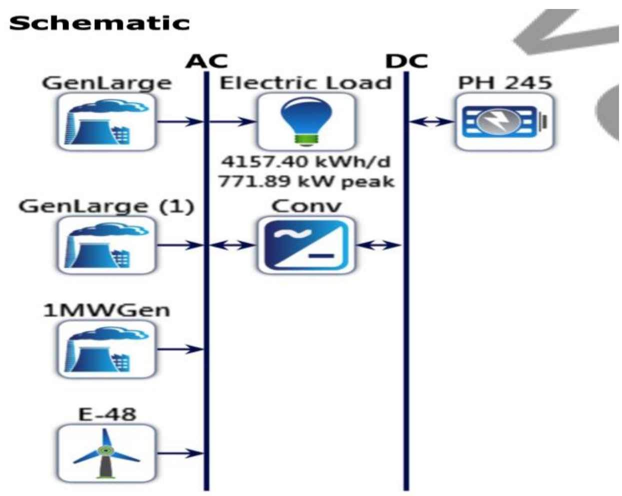

Fig. 4. Schematic diagram of the complete hybrid system

Other specifications for the Pumped Hydro storage are the nominal voltage of 240V, maximum charging current of 91.6A and maximum discharge current of 91.6A respectively.

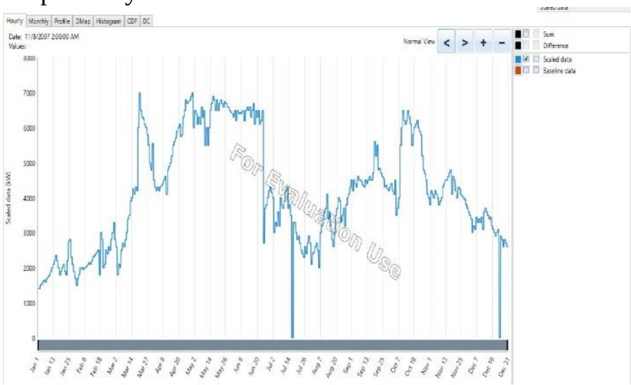

Fig. 5. HOMER representation of imported yearly load data

IV. RESULTS AND ANALYSES

Fig. 6. Comparison of the total power produced by generator (in black) with the total AC load demand (in blue)

TABLE II. ECONOMICAL VALUES FOR THE DIESEL GENERATORS

Component	Replacement cost ($)	O&M ($/op. hour) ($)	Initial capital cost($)
Generic 1000KW	42,106	6.177	400,000
Generic 500kW	21,053	3.089	200,000

TABLE III. OPTIMIZED ECONOMICAL RESULT FOR THE FIRST PROPOSED DESIGN

Operational cost ($)	Initial capital ($)	NPC (Net Present Cost) ($)	COE (Cost of energy) $/kW
4.78 million	3 million	64.8 million	0.138

In Fig. 6. the two graphs shows the comparison and impact of using 10disel generators without any wind turbine or energy storage system. The blue colour shows the total load demand for the year while the black colour graph shows the sum total of the optimized number of generators used. The black graph follows the same pattern with the blue graph indicating that the load demand has been attained. Similarly, Table III shows the optimized result from HOMER software based on the given input data. The software was able detect only seven 1000kw disel generators and one 500kw disel generator working and generated the most efficient result.

From Fig.7, the two graphs show the impact of using 7 diesel generators of 1000kw, 1 disel generator of 500kw and two 800kw each of E-48 wind turbine with no energy storage system. The gray colour shows the total load demand for the year while the black colour graph shows the sum total of the optimized number of power generation from the generators & wind turbines in the system.

Fig. 7. Comparison of the total power produced by generator (in black) with the total AC load demand (in grey)

TABLE IV. ECONOMICAL VALUES FOR THE DIESEL GENERATORS

Component	Replacement cost ($)	O&M ($/op. hour) ($)	Initial capital cost($)
Generic 1000KW	42,106	6.177	400,000
Generic 500kW	21,053	3.089	200,000

TABLE V. OPTIMIZED ECONOMICAL RESULT FOR THE SECOND PROPOSED DESIGN

Operational cost ($)	Initial capital ($)	NPC (Net Present Cost) ($)	COE (Cost of energy) $/kW
4.34 million	7.6 million	63.7 million	0.136

In addition, comparing Table III & V from the economical perspective, it can be seen that the second proposed design with 8 generators and two E-48 wind turbines is more feasible and preferred to the first design. This is because of its lower operational cost, cost of energy (COE) and Net present cost (NPC), although, the initial cost is higher.

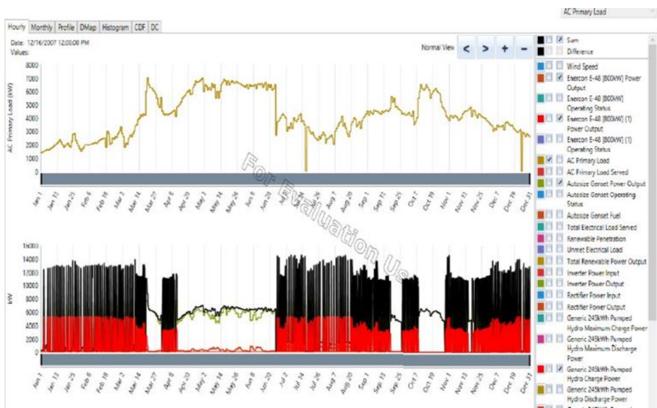

Fig. 8. The total amount of power produced by generator (in black), red region shows excess storage by pumped hydro compared with the total AC load demand (in grey)

TABLE VI. OPTIMIZED ECONOMICAL RESULT FOR THE THIRD PROPOSED DESIGN

Operational cost ($)	Initial capital ($)	NPC (Net Present Cost) ($)	COE (Cost of energy) $/kW
7.5 million	15.9 million	113 million	0.241

Moreover, from Fig. 8 it can be deduced that the grey graph shows the total load demand for the year while the black colour graph shows the sum total of the optimized number of power generated from the generators & the wind turbines in the system. Meanwhile the red graph indicates the excess power been stored by the hydro pumped system. The Table VI shows the economic effect of this design. It can be seen that the system is more expensive than the previous proposed designs. It also shows that when there is energy storage in the hybrid system, the price of electricity increases.

V. CONCLUSION

Three different hybrid systems topologies were designed and analyzed based on its economic value and maximum efficiency in meeting the load demand for Masirah Island in Oman. Several other economic analyses were also performed with the price of diesel at **0.48$/litre**. The optimized results also showed that whenever energy storage is added into the system, the cost of electricity increases. A wind-diesel hybrid system is feasible for Masirah Island because when E-48 wind turbine is integrated into the system, it reduces the cost compared to when running only diesel generator. The levelized cost of energy (COE) was found to be **$0.241/kW**.

ACKNOWLEDGEMENT

This research was supported by the Key Programme Special Fund under Grant No. [KSF-P-02]; and Suzhou-Leuven IoT & AI cluster, AI University Research Centre (AI-URC) of the Xi'an Jiaotong-Liverpool University, China.

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